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PARTICLE-STRUCTURE INTERACTION USING CAD-BASED BOUNDARY DESCRIPTIONS AND ISOGEOMETRIC B-REP ANALYSIS (IBRA)

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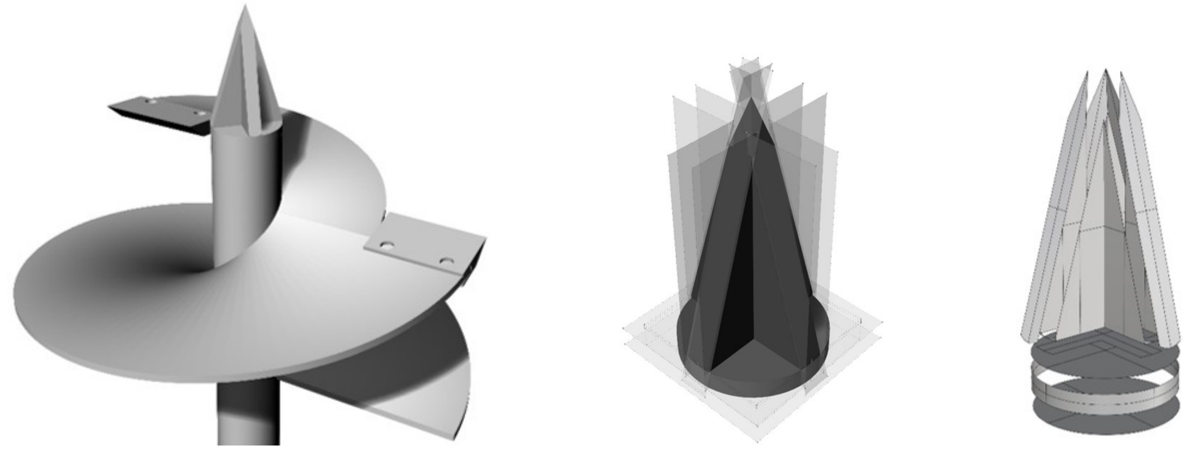
Abstract. The procedure and the properties with the use of NURBS-described CAD models in particle-structure interaction are presented within this contribution. This implies the needed entities of those models and the description of trimmed multipatches to discretize analysis suitable numerical models. Finally, the properties will be shown with some test cases in comparison to analytical benchmarks and simulations with FEM as boundary description.

1 INTRODUCTION

The integration of design in the simulation process became progressively important to allow more advanced monitoring, designing and modeling processes and higher qualities in solutions. Thus, the development of so called isogeometric methods raised and gained significance in science and industry. Those methods allow to bridge the gap between computer aided design (CAD) and numerical simulation without meshing or surface tesselation. Thus, no additional model error is introduced and the solution quality and convergence rate can be increased.

The given properties of the so called isogeometric B-Rep Analysis (IBRA) [1] can additionally be taken into account for different numerical methods in multiphysic simu-



(a) Rendered perspective view of CAD model.

(b) Untrimmed patches in transparent.

(c) Exploded view of multi-patches.

Figure 1: NURBS-based B-Rep CAD model of a soil driller. The hat of the driller is displayed once with the untrimmed patch descriptions and once with the exploded view of the trimmed patches of the structure.

lations. In those coupled approaches, the isogeometric description can be used as spatial delineation of boundaries but the structure can also interact and move with the external impacts. This means that using isogeometrically described structures in interaction with discrete particles, can provide more accurate results and allows to use the modeling advantages given due to the CAD integration.

2 ISOGEOMETRIC B-REP ANALYSIS (IBRA)

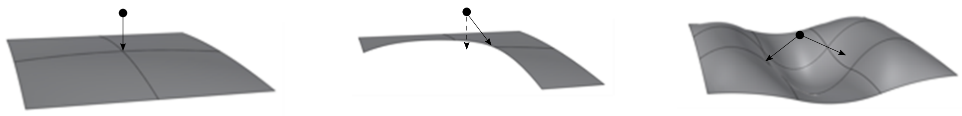
The *Isogeometric B-Rep Analysis* [1] can be seen as an extension to the *Isogeometric Analysis* (IGA) [3]. It enhances the approach with the spacial delineation of the NURBS-described geometry objects. IGA focuses on the use of surfaces (called patches) and curves, whereas IBRA allows to use cut, trimmed and coupled entities.

2.1 CAD model and Boundary Representation (B-Rep)

In Computer Aided Design, B-Rep is an approach to describe physical objects using their boundaries. It is containing to parts:

- *geometry* - defines the shape and the spatial position, curvature, ...
- *topology* - allows to link between geometrical entities and to enhance additional geometrical and physical information.

The three main topology entities are the *faces*, *edges* and *vertices.* That means, solids are described by a set of enclosing surfaces, faces by a surface and a set of underlying curves and edges by a curve and the boundary points. With this data type complex shapes can be described efficiently. In figure 1 is shown a advanced CAD-model which



(a) One surface

(b) Trimmed surface boundary edge

(c) Multiple projections

(d) Multiple surfaces

(e) One surface and one boundary

Figure 2: Different cases with multiple intersections for the projection towards B-Rep described NURBS-surfaces.

its respective components. Further information about how CAD-integrated simulations can be performed for structural analysis can be found in [1, 2]. Here are shown the requirements for analysis suitable CAD models.

2.2 Intersection with DEM-particles

Considering the high complexity of CAD models, many possible scenarios need to be considered. The most important cases are shown in figure 2.

(a) shows the standard case, of an interface within the middle of a surface.

(b) shows that the case not the closest point towards the surface is relevant because with trimmed patches, the closest point could be cut off.

(c-e) show special cases with multiple intersections. Here, more contact projections need to be performed.

With those intersections the needed interfaces can be formulated. Those need to transfer forces from the DEM particles to the IBRA geometries and obtain in return the distance, the relative displacement of the contact point within the last time step and the velocity of it. In IBRA one can not obtain the interface values directly on the degree of freedoms, thus, those have to be applied related to the shape functions of the location. The displacement and velocity at the interface point are computed as following. Those values are mapped to the discrete elements:

$$\mathbf{u}^j = \sum_{i=0}^{n_{cp}} N^i \cdot \mathbf{u}^i_{cp}; \quad \dot{\mathbf{u}}^j = \sum_{i=0}^{n_{cp}} N^i \cdot \dot{\mathbf{u}}^i_{cp} \tag{1}$$

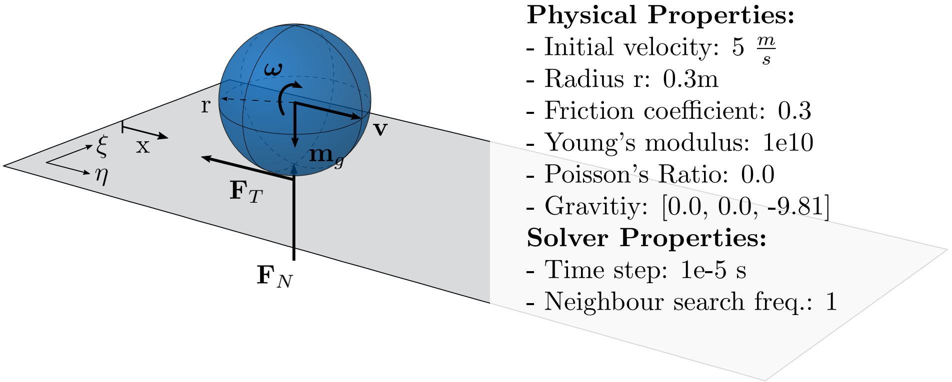
3 ANALYTICAL BENCHMARKS

In the following some benchmarks shall be described, to see, that with the use of the continuous NURBS-background the solution quality can be improved significantly. First, an example on a flat surface will be compared to the analytical solution and to a FEM simulation within the same solver framework. Second, an example on a curved shape will be either simulated on the exact geometry of the background and on a linearized discretization.

3.1 Sliding and Rolling Sphere

The following example has a particle rolling and sliding with an initial velocity over a flat plate. After a certain time the ball will slow down and keeps on rolling. The description of this problem is shown in figure 3. The simulation results are shown in figure 4. The comparison between IBRA, FEM and anyltical solution is described in table 1. The properties and the analytical solution of this simulation are adapted from [5]. With decreasing the time step, especially in the critical point, when the sliding stops and only rolling occurs, the results can be improved significantly.

To prove the generality of this approach different surface discretizations are tested with the same example. The surfaces were varied with a distortion of the control points and with multiple overlapping, coupled and trimmed patches. Some of the tested cases are shown in figure 5. It was possible to prove that the solution is not dependent on the modeling, as it is with finite elements, check table 1. As the solutions are identical, the results are not displayed separately.



Physical Properties:
- Initial velocity: 5 $\frac{m}{s}$
- Radius r: 0.3m
- Friction coefficient: 0.3
- Young's modulus: 1e10
- Poisson's Ratio: 0.0
- Gravitiy: [0.0, 0.0, -9.81]

Solver Properties:
- Time step: 1e-5 s
- Neighbour search freq.: 1

Figure 3: Description with physical and solver properties of ball rolling and sliding on plate.

3.2 Sphere Rolling on Brachistochrone

The Brachistochrone is one of the oldest optimization problems. It optimizes the shape of a surface on which a ball rolls the fastest from a higher point to lower one. The outcome is a curved surface with a new lowest point. For the chosen problem, the shape of the

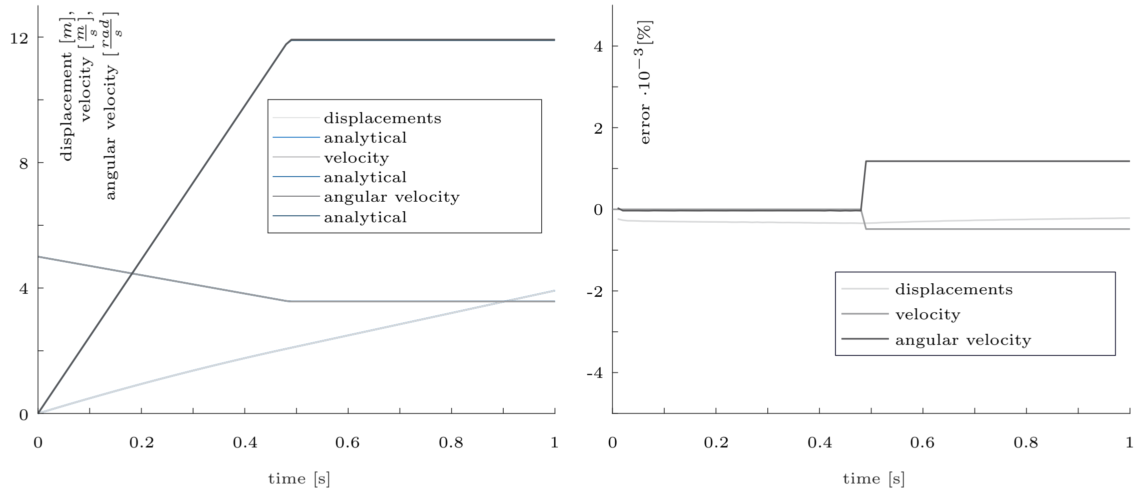


Figure 4: Comparison of analytical solution with coupled IBRA simulation.

	distance [m]	velocity $[\frac{\mathrm{m}}{\mathrm{s}}]$
Analytical solution	3.9182	3.5714
Quadrilateral mesh [5]	3.9021	3.5410
Triangle mesh [5]	3.9022	3.5410
IBRA	3.9173	3.5697

Table 1: Comparison of IBRA, 2 FEM discretizations and the analytical solution for sliding and rolling sphere on plate.

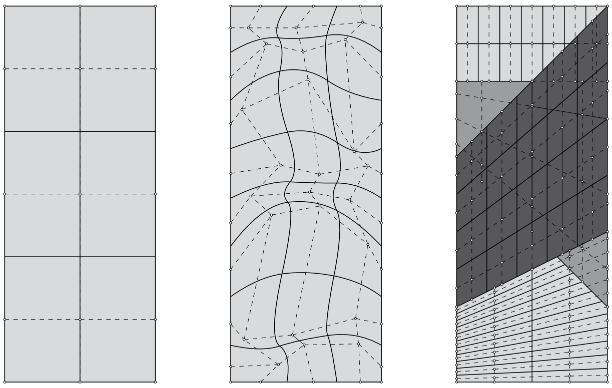
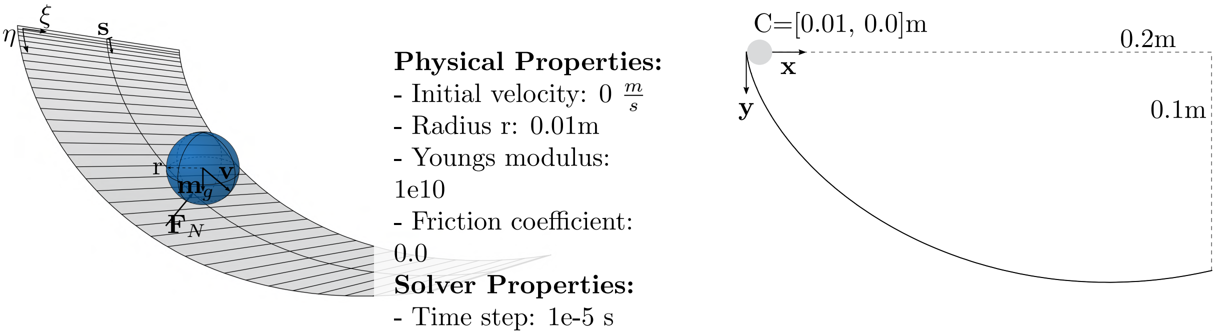


Figure 5: Different surface discretizations with same shape.



Physical Properties:
- Initial velocity: 0 $\frac{m}{s}$
- Radius r: 0.01m
- Youngs modulus: 1e10
- Friction coefficient: 0.0

Solver Properties:
- Time step: 1e-5 s

Figure 6: Description with physical properties and chosen parameters and shape of Brachistochrone.

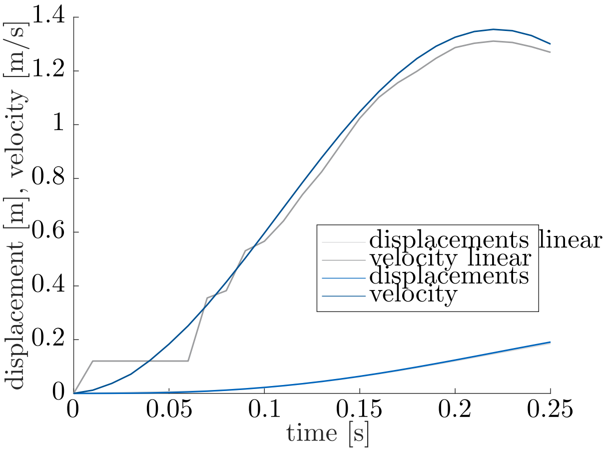


Figure 7: Comparison of displacement and velocity between the two discreizations: linear (gray) and high order (blue).

surface is described by:

$$\begin{aligned} x(s) &= r(s - \sin s) \\ y(s) &= r(1 - \cos s) \end{aligned} \tag{2}$$

In figure 6 is shown the surface and all the chosen parameters for the simulation. This example is adapted from [5]. This example is an ideal showcase to see that with a linearized surface, as a mesh, the solution weakens significantly in comparison to the exact geometry of the NURBS-surface.

In figure 7 is shown the comparison of the two different boundary walls. It can be seen that the sphere is jumping away after each section, within the linearized shape. This error can be reduced, by reducing the youngs modulus, however, this is not preferred in this case as then, the model would be modified. In this case one can see the advantages of using the exact surface as boundary delineation.

4 CONCLUSIONS

In this contribution the IBRA part was used as fixed boundary, however, it can also be extended in a multiphysics environment with a physical counter part on the IBRA surfaces, as for examples in [4]. Further, the complexity of the CAD models can also be improved, which was already tested and will be shown in upcoming publications.

The displayed approach, to use IBRA as boundary walls for DEM, eases the simulation process, the modeling procedure and can increase the solution quality and the stability of the simulation. The advantages of using IBRA are summarized as following:

- No additional model, as linearized FEM-meshes need to be introduced. This allows a direct cast from CAD to the solver.

- Keeping the geometry description and the high-order shape avoids to introduce modeling errors. This is essential for simulations, where a high accuracy is needed. The advantages of NURBS can be seen especially with e.g. bearings, curve shapes as cones, ...

- The continuous shape needs less contact interfaces and thus less evaluation of interface areas. At the mesh boundaries special treatment need to be done to keep physical correctness. IBRA keeps the full patches which are generally bigger and thus, not that many cell jumps are occurring. For some simulation this can lead to a higher stability and a better quality.

Disadvantages with the use of CAD models:

- Higher complexity of CAD model in comparison to linearized meshes. Models need to be included with the entire CAD topology and have to be treated accordingly. However, this additional information can also be advantageous in certain parts of the simulation.

- CAD models which are used for design can come with a not sufficient quality for numerical analyses. The same problem occurs if those need to be meshed, however, sometimes mesh cleaning can be simpler than CAD model cleaning.

- Depending on the model, higher computational costs for projections, including special treatment of the contact interface points (see figure 2). Need of considering multiple local optima in one boundary object for the contact to the DEM-particles.

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